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GEOLOGICAL HISTORY

OF THE

YELLOWSTONE NATIONAL PARK.

BY
ARNOLD HAGUE,
UNITED STATES GEOLOGICAL SURVEY

A PAPER PRESENTED AT THE UTAH AND MONTANA MEETING OF THE
AMERICAN INSTITUTE OF MINING ENGINEERS, JULY, 1887.

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GEOLOGICAL HISTORY OF THE YELLOWSTONE NATIONAL PARK.

BY ARNOLD HAGUE, U. S. GEOLOGICAL SURVEY.

IN the short time allotted to me* I can only hope to present to you a brief sketch of the main geological features of the country which you are about to visit. My remarks must, of necessity, be more or less incomplete, as my desire is not so much to elucidate any special problem connected with the many interesting geological questions to be found here, as rather to offer such a general view of the region as will enable you, during your five days' trip through the Park, to understand clearly something of its physical geography and geology.

The Yellowstone Park is situated in the extreme northwestern portion of the Territory of Wyoming. Its boundaries, as determined by the original Act of Congress setting apart the Park, are very ill-defined. At the time of the enactment of the law establishing this national reservation, the region had been but little explored, and its relation to the physical features of the adjacent country was but little understood. Since that time, surveys have shown that only a narrow strip, about two miles in width, was situated in the Territory of Montana, but it was also found that a still narrower strip extended westward into the Territory of Idaho. The question of properly establishing the boundaries, based upon our present knowledge of the country, is now before Congress, and an Act has already passed the Senate, proposing to make the northern boundary coincide with the boundary between Wyoming and Montana, and the western boundary coincide with the Wyoming and Idaho line. The Act under consideration extends the southern boundary of the Park to the 44th parallel of latitude, carrying the area of the reservation southward nine and one-half miles. The eastern boundary is made to coincide with the meridian of 109° 30′, adding a strip of country about twenty-four and one-half miles in width along the entire eastern side of the Park.

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* This paper was presented as an address, given at a special session of the Institute, at Mammoth Hot Springs, Wyoming, on the borders of the National Park.

The area of the Park, as at present defined, is somewhat more than 3000 square miles, and the proposed addition increases the reservation by nearly 2000 square miles. The Park plateau, with the adjacent mountains, presents a sharply defined region, in strong contrast with the rest of the northern Rocky Mountains. It stands out boldly by itself, unique in topographical structure, and complete as a geological problem.

The central portion of the Yellowstone Park is, essentially, a broad, elevated, volcanic plateau, between 7000 and 8500 feet above sea-level, and with an average elevation of about 8000 feet. Surrounding it on the south, east, north, and northwest, are mountain ranges with culminating peaks and ridges rising from 2000 to 4000 feet above the general level of the enclosed table-land.

For present purposes it is needless to confine ourselves strictly to legal boundaries, but rather to consider the entire region in its broader physical features. It is worthy of note, however, that by the proposed enlargement the protected area will agree closely with the geographical province.

South of the Park, the Tetons stand out prominently above the surrounding country, the highest, grandest peaks in the northern Rocky Mountains. The eastern face of this mountain mass rises with unrivalled boldness for nearly 7000 feet above Jackson Lake. Northward, the ridges fall away abruptly beneath the lavas of the Park, only the outlying spurs coming within the limits of the reservation. For the most part the mountains are made up of coarse crystalline gneisses and schists, probably of Archæan age, flanked on the northern spurs by Paleozoic sediments.

To the eastward, across the broad valley of the Upper Snake, generally known as Jackson Basin, lies the well-known Wind River Range, famous from the earliest days of the Rocky Mountain trappers. The Northern end of this range is largely composed of Mesozoic strata, single ridges of Cretaceous sandstone penetrating still farther northward into the regions of the Park, and protruding above the great flows of lava.

Along the entire eastern side of the Park stretches the Absaroka Range—so-called from the Indian name of the Crow Nation. The Absaroka Range is intimately connected with the Wind River, the two being so closely related that any line of separation must be drawn more or less arbitrarily, based more upon geological structures and forms of erosion than upon physical limitations.

The Absarokas offer, for more than eighty miles, a bold, unbroken barrier to all western progress; a rough, rugged country, dominated by high peaks and crags from 10,000 to 11,000 feet in height. Only a few adventurous hunters and mountaineers cross the range by one or two dangerous, precipitous trails known to but few. The early trappers found it a forbidding land; prospectors who followed them, a barren one.

At the northeast corner of the Park a confused mass of mountains connects the Absarokas with the Snowy Range. This Snowy Range shuts in the Park on the north, and is an equally rough region of country, with elevated mountain masses covered with snow the greater part of the year, as the name would indicate. Only the southern slopes, which rim in the Park region, come within the limit of our investigation. Here the rocks are mainly granites, gneisses, and schists, the sedimentary beds, for the most part, referable to the pre-Cambrian series.

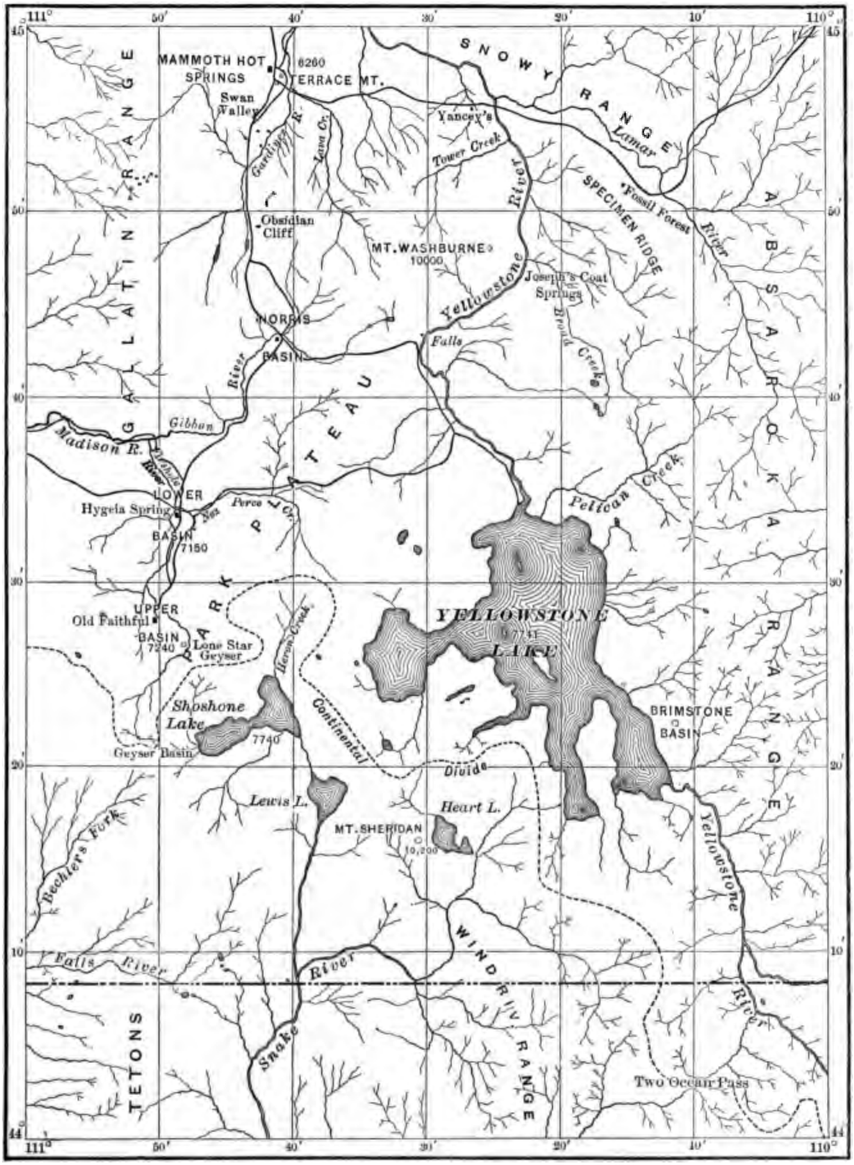
The Gallatin Range encloses the Park on the north and northwest. It lies directly west of the Snowy, only separated by the broad valley of the Yellowstone River. It is a range of great beauty, of diversified forms, and varied geological problems. Electric Peak, in the extreme northwestern corner of the Park, is the culminating point in the Range, and affords one of the most extended views to be found in this part of the country. Archæan gneisses form a prominent mass in the range, over which occur a series of sandstones, limestones, and shales, of Paleozoic and Mesozoic age, representing Cambrian, Silurian, Devonian, Carboniferous, Trias, Jura, and Cretaceous. Immediately associated with these sedimentary beds, are large masses of intrusive rocks, which have played an important part in bringing about the present structural features of the range. They are all of the andesitic type, but showing considerable range in mineral composition, including pyroxene, hornblende, and hornblende-mica varieties. These intrusive masses are found in narrow dikes, in immense interbedded sheets forced between the different strata, and as laccolites, a mode of occurrence first described from the Henry Mountains in Utah, by Mr. G. K. Gilbert, but now well recognized elsewhere in the northern Cordillera.

We see, then, that the Absarokas rise as a formidable barrier on the eastern side of the Park, the Gallatins as a steep mural face on the west side, while the other ranges terminate abruptly, rimming in the Park on the north and south, and leaving a depressed region not unlike the parks of Colorado, only covering a more extended area with a relatively deeper basin. The region has been one of profound dynamic action, and the centre of mountain building on a grand scale. On the accompanying map of the Yellowstone Park, which shows the position of the principal objects of interest, the relations of the ranges to the plateau are clearly indicated.

It is not my purpose at the present time to enter upon the details of geological structure of these ranges, each offering its own special study and field of investigation. My desire is simply to call your attention to their general features and mutual relations. So far as their age is concerned, evidence goes to show that the action of upheaval was contemporaneous in all of them, and coincident with the powerful dynamic movements which uplifted the north and south ranges, stretching across Colorado, Wyoming, and Montana. This dynamic movement blocked out, for the most part, the Rocky Mountains, near the close of the Cretaceous, although there is good reason to believe that in this region profound faulting and displacement continued the work of mountain building well into the Middle Tertiary period.

Throughout Tertiary time in the Park area, geological history was characterized by great volcanic activity, enormous volumes of erupted material being poured out in the Eocene and Middle Tertiary continuing with less force through the Pliocene, and extending into Quaternary time. Within very recent times there is no evidence of any considerable outburst; indeed, the region may be considered long since extinct. These volcanic rocks present a wide range in chemical and mineral composition and physical structure. They may all, however, be classed under three great groups—andesites, rhyolites, and basalts—following each other in the order named. In some instances, eruptions of basalt occurred before the complete extinction of rhyolite, but in general, the relative age of each group is clearly and sharply defined, the distribution and mode of occurrence of each presenting characteristic and salient features frequently marked by periods of erosion.

Andesites are the only volcanic rocks which have played an important part in producing the present structural features of the mountains surrounding the Park. As already mentioned, they occur in large masses in the Gallatin Range, while most of the culminating peaks in the Absarokas are composed of compact andesites and andesitic breccias. On the other hand, the andesites are not confined to the mountains, but played an active rôle in filling up the interior basin. That the duration of the andesitic eruptions was long continued, is made evident by the plant-remains found in ash and lava beds through 2000 feet of volcanic material. The plants have as yet been too little studied to define positively their geological



Scale: 1 inch—12 miles. YELLOWSTONE NATIONAL PARK AM. BANK NOTE CO. N. Y.

horizons. It is quite possible that they may indicate marked differences of climate between the lower and upper beds.

In early Tertiary times, a volcano burst forth in the northeast corner of the depressed area encircled by the Park Mountains, not far from the junction of the Absaroka and Snowy Ranges. While not to be compared in size and grandeur with the volcanoes of California and the Cascade Range, it is, for the Rocky Mountains, one of no mean proportions. It rises from a base about 6500 feet above sea-level, the culminating peak attaining an elevation of 10,000 feet. This gives a height to the volcano of 3500 feet from base to summit, measuring from the Archæan rocks of the Yellowstone Valley to the top of Mount Washburne. The average height of the crater rim is about 9000 feet above sea-level, the volcano measuring 15 miles across the base. The eruptive origin of Mount Washburne has long been recognized, and it is frequently referred to as a volcano. It is, however, simply the highest peak among several others, and represents a later outburst which destroyed in a measure the original rim and form of the older crater. The eruptions for the most part were basic andesites. Erosion has so worn away the earlier rocks, and enormous masses of more recent lavas have so obscured the original form of the lava-flows, that it is not easy for the inexperienced eye to recognize a volcano and the surrounding peaks as the more elevated points in a grand crater wall. By following around on the ancient andesitic rim, and studying the outline of the old crater, together with the composition of its lavas, its true origin and history may readily be made out. This older crater has, as yet, received no special designation, but when our maps and reports are finally published, this ancient geological ruin will receive an appropriate designation. This old volcano of early Tertiary time occupies a prominent place in the geological development of the Park, and dates back to the earliest outbursts of lava which have in this region changed a depressed basin into an elevated plateau. We have here a volcano situated far inland, in an elevated region, in the heart of the Rocky Mountains. It lies on the eastern side of the continent, only a few miles from the great continental divide which sends its waters to both the Atlantic and Pacific.

After the dying out of the andesitic lavas, followed by a period of erosion, immense volumes of rhyolite were erupted, which not only threatened to fill up the crater but to bury the outer walls of the volcano. On all sides the andesitic slopes were submerged beneath the rhyolite to a height of from 8000 to 8500 feet. This enormous mass of rhyolite, poured out after the close of the andesitic period, did more than anything else to bring about the present physical features of the Park table-land. A tourist making the customary trip through the Park, visiting all the prominent geyser basins, hot springs, and the Grand Cañon and Falls of the Yellowstone, is not likely to come upon any other rock than rhyolite, excepting, of course, deposits from the hot springs. If he extended his journey to the lake-region, taking in Shoshone, Lewis, and Yellowstone lakes, and spending a week or ten days going over the beaten routes of travel, he will not, unless he ascends Mount Washburne, leave the rhyolite lavas. A description of the rhyolite region is essentially one of the Park plateau. Taking the bottom of the basin at 6500 feet above sea-level, these acidic lavas were piled up until the accumulated mass measured 2000 feet in thickness. It completely encircled the Gallatin Range, burying its lower slopes on both the east and west sides; it banked up all along the west flanks of the Absarokas, and buried the outlying spurs of the Teton and Wind River Ranges.

The Park Plateau covers an area approximately 50 by 40 miles, with a mean altitude of 8000 feet. It is accidented by undulating basins of varied outline and scored by deep cañons and gorges. Strictly speaking, it is not a plateau, at least it is by no means a level area, but a rugged country, characterized by bold escarpments and abrupt edges of mesa-like ridges. But few large vents or centers of volcanic activity for the rhyolite, have been recognized, the two principal sources being the volcano to which reference has already been made, and Mount Sheridan in the southern end of the Park. Mount Sheridan is the most commanding peak on the plateau, with an elevation of 10,200 feet above sea-level and 2600 feet above Heart Lake. From the summit of the peak on a clear day one may overlook the entire plateau country and the mountains which shut it in, while almost at the base of the peak lie the magnificent lakes which add so much to the quiet beauty of the region, in contrast with the rugged scenery of the mountains. From no point is the magnitude and grandeur of the volcanic region so impressive. The lava-flows, bounded on the east by the Absarokas, extend westward not only across the Park but across the Madison Plateau and out on to the great plains of Snake River, stretching far to the westward almost without a break in the continuity of the eruptive flows. Over the central portion of the Park, where the rhyolites are thickest, erosion has failed to penetrate to the underlying rock. Even such deep gorges as the Yellowstone, Gibbon and Madison Cañons have nowhere worn through these rhyolite flows. In the

Grand Cañon of the Yellowstone the andesitic breccias are found beneath the rhyolites, but the deepest cuts fail to reveal the underlying sedimentary beds. Although the rocks of the plateau for the most part belong to one group of acidic lavas, they by no means present the great uniformity and monotony in field appearance that might be expected. These 2000 square miles offer as grand a field for the study of structural forms, development of crystallization and mode of occurrence of acidic lavas as could well be found anywhere in the world. They vary from a nearly holocrystalline rock to one of pure volcanic glass. Obsidian, pumice, pitchstone, ash, breccia and an endless development of transition forms alternate with the more compact lithoidal lavas which make up the great mass of the rhyolite, and which in color, texture and structural development present an equally varied aspect. In mineral composition these rocks are simple enough. The essential minerals are orthoclase and quartz, with more or less plagioclase. Sanidine is the prevailing feldspar, although in many cases plagioclase forms occur nearly as abundantly as orthoclase. Chemical analyses, whether we consider the rocks from the crater of Mount Sheridan, the summit of the plateau, or the volcanic glass of the world-renowned Obsidian Cliff, present comparatively slight differences in ultimate composition.

The following analyses of two rocks, representing extreme forms in physical habit, show how closely they approach each other in composition of the original magma.

	No. 1. Madison Plateau.	No. 2. Obsidian Cliff.
Silica,	75.19	75.52
Titanic acid,	none	none
Phosphoric acid,	none	none
Alumina,	13.77	14.11
Ferric oxide,	0.61	1.74
Ferrous oxide,	1.37	0.08
Ferric sulphide,	......	0.11
Manganese oxide,	trace	none
Lime,	0.68	0.78
Magnesia,	0.09	0.10
Lithia,	0.02	......
Potash,	3.33	3.62
Soda,	3.83	3.93
Sulphuric acid,	0.29	......
Water,	0.65	......
Ignition,	......	0.39
Total,	99.83	100.38

The rock from Madison Plateau was collected on the north side of Madison Cañon and was selected as a typical rock covering large areas of the Park. It is purplish-gray in color, rough in texture, porphyritic in structure, and characterized by well-developed sanidin and quartz. The obsidian, from Obsidian Cliff, is an excellent example of pure volcanic glass, wholly devoid of porphyritic crystals. In general the investigations of the laboratory confirm the observations of the field-geologist, that the differences exhibited by the volcanic product is not one of chemical or mineral composition, but rather of physical conditions under which the magma has cooled.

I have dwelt somewhat in detail upon the nature of these rocks for two reasons: *first*, because of the difficulty met with by the scientific traveller in recognizing the uniformity and simplicity of chemical composition of the rhyolite magma over the entire plateau, owing to its great diversity in superficial habit; *second*, on account of their geological importance in connection with the unrivalled display of the geysers and hot springs. That the energy of the steam and thermal waters dates well back into the period of volcanic action, there is, in my opinion, very little reason to doubt. As the energy of this underground heat is to-day one of the most impressive features of the country, I will defer commenting upon the geysers and hot springs until speaking of the present condition of the Park.

Although the rhyolite eruptions were probably of long duration and died out slowly, there is, I think, evidence to show that they occupied a clearly and sharply defined period between the andesites and basalt eruptions. Since the outpouring of this enormous body of rhyolite and building up of the plateau the region has undergone profound faulting and displacement, lifting up bodily immense blocks of lava and modifying the surface features of the country. Following the rhyolite came the period of basalt eruptions, which in comparison with the andesite and rhyolite eras was, so far as the Park was concerned, insignificant, both as regards the area covered by the basalt and its influence in modifying the physical aspect of the region. The basalt occurs as thin sheets overlying the rhyolite and in some instances as dikes cutting the more acidic rocks. It has broken out near the outer edge of the rhyolite body and occurs most frequently along the Yellowstone Valley, along the western foothills of the Gallatin Range and Madison plateau and again to the southward of the Falls River basin.

After the greater part of the basalt had been poured out came the glacial ice, which widened and deepened the pre-existing drainage-channels, cut profound gorges through the rhyolite lavas and modelled the two volcanoes into their present form. Over the greater part of the Cordillera of the central and northern Rocky Mountains, wherever the peaks attain a sufficiently high altitude to attract the moisture-laden clouds, evidences of the former existence of local glaciers are to be found. In the Teton Range several well-defined characteristic glaciers still exist upon the abrupt slopes of Mount Hayden and Mount Moran. They are the remnants of a much larger system of glaciers. The Park region presents so broad a mass of elevated country that the entire plateau was, in glacial times, covered with a heavy capping of ice. Evidences of glacial action are everywhere to be seen.

Over the Absaroka Range glaciers were forced down into the Lamar and Yellowstone Valleys, thence westward over the top of Mount Evarts to the Mammoth Hot Springs basin. On the opposite side of the Park the ice from the summit of the Gallatin Range moved eastward across Swan Valley and passing over the top of Terrace Mountain joined the ice-field coming from the east. The united ice-sheet plowed its way northward down the valley of the Gardiner to the Lower Yellowstone where the broad valley may be seen strewn with the material transported from both the east and west rims of the Park.

Since the dying out of the rhyolite eruptions erosion has greatly modified the entire surface features of the Park. Some idea of the extent of this action may be realized when we recall that the deep cañons of the Yellowstone, Gibbon and Madison Rivers—cañons in the strictest use of the word—have all been carved out since that time. To-day these gorges measure several miles in length and from 1000 to 1500 feet in depth.

To the geologist one of the most impressive objects on the Park Plateau is a transported boulder of granite which rests directly upon the rhyolite near the brink of the Grand Cañon about three miles below the Falls of the Yellowstone. It stands alone in the forest, miles from the nearest glacial boulder. Glacial detritus carrying granitic material may be traced upon both sides of the cañon wall, but not a fragment of an older rock, more than a few inches in diameter, has been recognized within a radius of many miles. This massive block, although irregular in shape and somewhat pointed towards the top measures 24 feet in length by 20 feet in breadth and stands

18 feet above the base. The nearest point from which it could have been transported is distant 30 or 40 miles. Coming upon it, in the solitude of the forest with all its strange surroundings, it tells a most impressive story. In no place are the evidences of frost and fire brought so forcibly together as in the Yellowstone National Park.

Since the close of the ice period no geological events of any moment have brought about any changes in the physical history of the region other than those produced by the direct action of steam and thermal waters. A few insignificant eruptions have probably occurred, but they failed to modify the broad outlines of topographical structure and present but little of general interest beyond the evidence of the continuance of volcanic action into quaternary times. Volcanic activity in the Park may be considered as long since extinct. At all events indications of fresh lava-flows within historical times are wholly wanting. This is not without interest, as evidence of underground heat may be observed everywhere throughout the Park in the waters of the geysers and hot springs. All our observations point in one direction and lead to the theory that the cause of the high temperatures of these waters must be found in the heated rocks below, and that the origin of the heat is in some way associated with the source of volcanic energy. It by no means follows that the waters themselves are derived from any deep-seated source; on the contrary, investigation tends to show that the waters brought up by the geysers and hot springs are mainly surface waters which have percolated downwards a sufficient distance to become heated by large volumes of steam ascending through fissures and vents from much greater depths. If this theory is the correct one, it is but fair to demand that evidence of long-continued action of hot waters and superheated steam should be apparent upon the rocks through which they passed on their way to the surface. This is precisely what one sees in innumerable places on the Park plateau. Indeed, the decomposition of the lavas of the rhyolite plateau have proceeded on a most gigantic scale, and could only have taken place after the lapse of an enormous period of time, and the giving off of vast quantities of heat, if we are to judge at all by what we see going on around us to-day. The ascending currents of steam and hot water have been powerful geological agents, and have left an indelible impression upon the surface of the country. The most striking example of this action is found in the Grand Cañon of the Yellowstone. From the lower falls for three miles down the river the abrupt walls upon both sides of the cañon, a thousand feet in depth, present a brilliancy and mingling of color beyond the power of description. From the brink of the cañon to the water's edge, the walls are sheer bodies of decomposed rhyolite. Varied hues of orange, red, purple, and sulphur-yellow, are irregularly blended in one confused mass. There is scarcely a piece of unaltered rock in place. Much of it is changed into kaolin, but from rhyolite, still easily recognized, occur transition products of every possible kind to good porcelain clay. This is the result of the long-continued action of steam and vapors upon the rhyolite lavas. Through this mass of decomposed rhyolite the course of ancient steam vents in their upward passage may still be traced, while at the bottom of the cañon hot springs, fumaroles, and steam vents, are still more or less active, but probably with diminished power.

It is needless to weary you with the details of this decomposition, but I may add that investigations in the laboratory upon these transition-products fully substantiate field observations.

Still other areas are quite as convincing, if not on so grand a scale, as the Yellowstone Cañon. Joseph's Coat Basin, on the east side of the cañon, and Brimstone Hills, on the east side of the Yellowstone Lake, an extensive area on the slopes of the Absaroka Range, both present evidences of the same chemical processes brought about in the same manner. It is not stating it too strongly to say that the plateau on the east side of the Grand Cañon, from Broad Creek to Pelican Creek, is completely undermined by the action of superheated steam and alkaline waters on the rhyolite lava. The same processes may be seen going on to-day in all the geyser basins. To accomplish these changes a long period of time must have been required. The study of comparatively fresh vents show almost no change from year to year, although careful scrutiny during a period of five years detects a certain amount of disintegration, but infinitely small in comparison with the great bodies of altered rock. This is well shown in a locality like the Monarch Geyser in the Norris Geyser Basin, where the water is thrown out at regular intervals through a narrow fissure in the rock.

The Grand Cañon of the Yellowstone offers one of the most impressive examples of erosion, on a grand scale, within recent geological times. It is self-evident that the deep cañon must be of much later origin than the rock through which it has been worn, and it seems quite clear that the course and outlines of the cañon were in great part determined by the easily eroded decomposed material forming the cañon walls, and this, in turn, was brought about by the slow processes just described.

The evidence of the antiquity of the hot spring deposits is, perhaps, shown in an equally striking manner, and by a wholly different process of geological reasoning. Terrace Mountain is an outlying ridge of the rhyolite plateau just west of the Mammoth Hot Springs. It is covered on the summit with thick beds of travertine, among the oldest portions of the Mammoth Hot Springs deposits. It is the mode of occurrence of these calcareous deposits from the hot waters which have given the name to the mountain. Lying upon the surface of this travertine on the top of the mountain are found glacial boulders brought from the summit of the Gallatin Range, fifteen miles away, and transported on the ice-sheet across Swan Valley and deposited on the top of the mountain, 700 feet above the intervening valley. It offers the strongest possible evidence that the travertine is older than the glacier which has strewn the country with transported material. How much travertine was eroded by the ice is, of course, impossible to say, but so friable a material would yield readily to glacial movement.

Still another method of arriving at the great antiquity of the thermal energy, and the age of the hot-spring formation, is by determining the rate of deposition and measuring the thickness of the accumulated sinter. This method, although the one which would perhaps first suggest itself, is, in my opinion, by no means as satisfactory as the geological reasoning already given. It is unsatisfactory because no uniform rate of deposition can be ascertained for even a single area, like the Upper Geyser Basin, and it is still more difficult to arrive at any conclusion as to the growth of the sinter in the past. Moreover, it is quite possible that heavy deposits may have suffered erosion before the present sinter was laid down. It, however, corroborates other methods, and possesses the advantage of being a direct way.

It may be well to add here that there exists the greatest contrast between the deposits of the Mammoth Hot Springs and those found upon the plateau. At the Mammoth Springs they are nearly pure travertine, with only a trace of silica, analyses showing from 95 to 99 per cent. of calcium carbonate. On the plateau, the deposits consist for the most part of siliceous sinter, locally termed "geyserite." The reason for the difference is this: At the Mammoth Hot Springs the steam, although ascending from fissures in the igneous rocks, comes in contact with the waters found in the Mesozoic strata, which here form the surface-rocks. The Jura or Cretaceous limestones have furnished the lime held in solution and precipitated on the surface as travertine. On the other hand, the mineral constituents of the plateau waters are derived almost exclusively from the highly acidic lavas, which, as it will be seen by reference to the analyses, carry but a small amount of lime.

Deposition of sinter from the hot waters of the geyser basins depends in a great measure on the amount of silica held in solution, which varies considerably at the different localities, and may have varied still more in past time. The silica, as determined by analyses, ranges from .22 to .60 grammes per kilogramme of water, the former being the amount found in the water of the caldron of the Excelsior Geyser, and the latter at the Coral Spring in the Norris Basin. Analysis shows that from one-fifth to one-third of the mineral matter held in solution consists of silica, the remaining constituents being readily soluble salts carried off by the surface drainage. A few springs highly charged with silica, like the Coral, deposit it on the cooling of the waters; but such springs, however, are exceptional, and I do not recall a single instance of a spring in the Upper Geyser Basin precipitating silica in this way. At most springs and geysers it results only after evaporation, and not from mere cooling of the water. It seems probable that the nature and amount of alkaline chlorides and carbonates present influence the separation of silica. Temperature also may in some degree influence the deposition. My friend, Mr. Elwood Hofer, one of the best guides to this region, and a keen observer of nature, has called my attention to an observation of his made in mid-winter, while on one of his snow-shoe trips through the Park. He noticed that certain overflow pools of spring-water, upon being frozen, deposited a considerable amount of mineral matter. He has sent me specimens of this material which, upon examination, proved to be identical with the silica deposited from the Coral Spring upon the cooling of the water. Demijohns of geyser water which have been standing for one or two years have failed to precipitate any silica. Quite recently, in experimenting upon these waters in the laboratory, it was noticed that on reducing them nearly to the freezing point no change took place, but upon freezing the waters there was an abundant separation of free silica. The waters frozen in this way were collected from the Coral Spring, Norris Basin, and the Taurus Geyser, Shoshone Basin.

Again, there is no doubt that the algeous growths found flourishing in the hot waters of the Park favor the secretion of silica, and exert an influence in building up the geyserite far greater than one would at first be led to suppose. These low forms of vegetable life occur in nearly all pools, springs, and running-waters up to a temperature of 185° Fahr., only 13° below the boiling point, at the Upper Geyser Basin. If time permitted, much might be said on this subject. I will only add, that Mr. Walter H. Weed, in connection with his other duties on the Geological Survey, has devoted much time to a study of these algeous growths, and the results of his investigations will form an important chapter in the final publications.

Several methods have been devised for ascertaining the growth of deposition of the geyserite. One way is by allowing the water to trickle over twigs, dried grasses, or almost anything exposing considerable surface, and noting the amount of incrustration. This way gives the most rapid results, but is far from satisfactory, and by no means reproduces the conditions existing in nature. Other methods employed are, placing objects on the surface of the water, or, still better, partially submerging them in the hot pools, or again by allowing the water to run down an inclined plane with frequent intervals for evaporation and concentration.

The vandals who delight to inscribe their names in public places have invaded the geyser basins in large numbers, and left their addresses upon the geyserite in various places. It is interesting to note how quickly these inscriptions become indelible by the deposition of the merest film of silica upon the lead pencil marks, and, at the same time, how slowly they build up. Names and dates known to be six and eight years old remain perfectly legible, and still retain the color and lustre of the graphite. That there is some increase in the thickness of the incrustation is evident, although it grows with incredible slowness. Mr. Weed tells me that he has been able, in at least one instance, to chip off this siliceous film and reproduce the writing with all its original distinctness, showing conclusively that a slow deposition has taken place. Pencil inscriptions upon the siliceous sinter at Rotomahana Lake, in New Zealand, are said to be legible after the lapse of twenty or thirty years. It is easy to see that various ingenious devices might be planned to estimate the rate of deposition, but in my opinion none of them equal a close study of the conditions found in nature, especially where investigations of this kind can be watched from year to year. All observations show an exceedingly slow building up of the geyserite formation. This is well seen in the repair going on where the rims surrounding the hot pools have been broken down, and where it might be supposed that the building-up process was under the most favorable conditions, yet, in a number of instances, I can see no appreciable change in three or four years. Revisiting hot springs in out-of-the-way places after several years absence, I am surprised to see that objects that I had noted carefully at the time remained unchanged. Taking the entire area of the Upper Geyser Basin covered by sinter, I believe that the development of the deposit does not exceed one-thirtieth of an inch a year, and this estimate I believe to be much nearer the maximum than the minimum rate of growth. The thickness of the geyserite has never been ascertained; the greatest thickness measured is 70 feet, the depth reached in the conduit of "Old Faithful" geyser, without meeting any obstruction. Supposing the deposit to have been built up with the same slowness as that going on to-day, and assuming it to grow at the rate given—one-thirtieth of an inch a year—it would require over 25,000 years to reach its present development. This gives us a great antiquity for the geyserite, but I believe that the deposition of the siliceous sinter in the Park has been going on for a still longer period of time. It is certain that the decomposition of the rhyolite of the plateau dates still further back.

From a geological point of view, there is abundant evidence that thermal energy is gradually becoming extinct. Tourists revisiting the Park, after an absence of two or three years, occasionally allude to the springs and geysers as being less active than formerly, and as showing indications of rapidly dying out. It is true that slight changes are constantly taking place, that certain springs become extinct or discharge less water, but this action is fully counterbalanced by increased activity in other localities. Close examination of the source of the thermal waters fails to detect any diminution in the supply. Moreover, it stands to reason that if the flow of these waters dated, geologically speaking, far back into the past, that the few years embraced within the historical records of the Park would be unable to indicate any perceptible change based upon a gradual diminution of the heat. Accurate descriptions of the region go back only to 1871, the year of the first exploration by Dr. F. V. Hayden.

The number of geysers, hot springs, mud-pots and paint-pots scattered over the Park exceeds 3500, and if to these be added the fumaroles and solfataras from which issue in the aggregate enormous volumes of steam and acid and sulphur vapors, the number of active vents would in all probability be doubled. Each one of these vents is a center of decomposition of the acid lavas. In the four principal geyser basins the geysers in action or known to have been active within the past sixteen years number 84. The following list comprises all the geysers that are known in the Norris, Lower, Midway, and Upper Geyser Basins.

Norris Geyser Basin.—14.

Arsenic,
Constant,
Echinus,
Fearless,
Fissure,
Growler,
Hurricane,
Minute,
Monarch,
Pearl,
Pebble,
Schlammkessel,
Veteran,
Vixen.

Lower Geyser Basin.—17.

Bead,
Clepsydra,
Conch,
Fountain,
Fitful,
Great Fountain,
Impulsive,
Jet,
Mound,
Narcissus,
Pink Cone,
Rosette,
Spasm,
Spray,
Steady,
Surprise,
White Dome.

Midway Geyser Basin.—4.

Excelsior,
Flood,
Rabbit,
Tromp.

Upper Geyser Basin.—40.

Artemesia,
Bee Hive,
Bijou,
Bonita,
Brilliant,
Bulger,
Cascade,
Castle,
Catfish,
Churn,
Cliff,
Comet,
Cubs,
Daisy,
Fan,
Giant,
Giantess,
Grand,
Grotto,
Infant,
Jewel,
Liberty,
Lion,
Lioness,
Mastiff,
Midget,
Model,
Mortar,
Oblong,
Old Faithful,
Restless,
Riverside,
Rocket,
Saw Mill,
Sentinel,
Shell,
Spasmodic,
Spanker,
Spiteful,
Splendid,
Sponge,
Spouter,
Sprinkler,
Sprite,
Tardy,
Three Sisters,
Triplets,
Turban,
White.

A comparative study of the analyses of the fresh rhyolite, the various transition-products and the thermal waters, points clearly to the fact that the solid contents of these waters are derived for the most part from the volcanic rocks of the plateau. During the progress of the work of the Geological Survey in the Yellowstone Park, there have been collected from nearly all the more important localities samples of the waters, which have been subjected to searching chemical analyses in the laboratory of the Survey by Messrs. F. A. Gooch and J. E. Whitfield, the results of whose work will be published at an early date.

The following analyses of hot waters from the three principal geyser basins, serve to shown their chemical composition :

	CONSTANT GEYSER.		HYGEIA SPRING.		OLD FAITHFUL.	
	Grams. per kilo. of water.	Per cent. of total mat. in solution.	Grams. per kilo. of water.	Per cent. of total mat. in solution.	Grams per. kilo. of water.	Per cent. of total mat. in solution.
Silica	0 4685	28.88	0.2477	20.98	0.3828	27.52
Sulph. acid	0.0923	5.69	0.0196	1.65	0.0152	1.09
Carbonic acid	0.0155	0.95	0.2907	24.62	0.0894	6 43
Boracic acid	0.0317	1.95	0.0239	2.02	0.0148	1.07
Arsenious acid	0.0018	0.11	0.0034	0.29	0.0021	0.15
Chlorine	0.5740	35.39	0.2487	21.06	0.4391	31.57
Bromine	trace	....	trace	....	0.0034	0.25
Hydr. sulph	none	....	none	....	0.0002	0.01
Oxygen (basic)	0.0185	1.14	0.0504	4.27	0.0419	3.02
Iron	trace	....	none	....	trace	....
Manganese	none	....	none	....	trace	....
Aluminium	0.0048	0.29	0.0036	0.31	0.0009	0 06
Calcium	0.0146	0.90	0.0064	0.54	0.0015	0.11
Magnesium	0.0018	0.11	0.0022	0.19	0.0006	0.04
Potassium	0.0745	4.60	0.0154	1.30	0.0267	1.92
Sodium	0.3190	19.67	0.2654	22.48	0.3666	26.36
Lithium	0.0030	0.19	0.0032	0.27	0.0056	0.40
Ammonium	0.00127	0.08	0.00021	0.02	0.00001	....
Hydr. (HCl)	0.0008	0.05	....	....	....	....
Caesium	....	....	....	....	trace	....
Rubidium	....	....	....	....	trace	....
Totals	1.62207	100.00	1.18081	100.00	1.39081	100.00

Constant Geyser, Norris Geyser Basin—Date of collection, September 13, 1885; temperature, 198° F.; reaction, slightly acid; specific gravity. 1.0011.

Hygeia Spring, Lower Geyser Basin—Date of collection, September 11, 1885; temperature, 109° F.; reaction, alkaline; specific gravity, 1.0010.

Old Faithful Geyser, Upper Geyser Basin--Date of collection, September 1, 1884; temperature, 190° F.; reaction, alkaline; specific gravity, 1.00096.

They are all siliceous alkaline waters holding the same mineral constituents but in varying quantities. Silica forms the principal deposit not only immediately around the springs, but over the entire floor of the basins. The carbonates, sulphates, chlorides and traces of other easily soluble salts are carried off in the waters. Oxides of iron and manganese and occasionally some calcite occur under certain conditions in the caldrons of the hot springs or immediately around their vents. Concentrations from large quantities of these waters fail to show the presence of even a trace of copper, silver, tin or other metal. Nearly all the waters carry arsenic, the amount present, according to Messrs. Gooch and Whitfield, varying from .02 to .25 per cent. of the mineral matter in solution.

Among the incrustations found at several of the hot springs and geysers is a leek-green amorphous mineral, which proves on investigation to be scorodite, a hydrous arseniate of iron. The best occurrence observed is at Joseph's Coat Springs, on the east side of the Grand Cañon of the Yellowstone, where it occurs as a coating upon the siliceous sinter lining the caldron of a boiling spring. Analysis shows a nearly pure scorodite, agreeing closely with the theoretical composition.

Ferric oxide,	34.94
Arsenic acid,	48.79
Water,	16.27
	100.00

Alteration of the scorodite into limonite takes place readily, which in turn undergoes disintegration by the wearing of the water, and is mechanically carried away. So far as I know this is the only occurrence where scorodite has been recognized as deposited from the waters of thermal springs. Although pure scorodite is only sparingly preserved at a few localities in the Yellowstone Park, it is easily recognized by its characteristic green color, in strong contrast with the white geyserite and yellow and red oxides of iron. After a little practice the mineral green of scorodite is not easily mistaken for the vegetable green of the algeous growths. The latter is associated everywhere with the hot waters, while the former, an exceedingly rare mineral, is obtained only in small quantities after diligent search. In America traces of arsenic have been reported from several springs in Virginia and quite recently sodium arseniate has been detected in the hot springs of Ashe County, North Carolina. Arsenical waters of sufficient strength to be beneficial for remedial purposes and not otherwise deleterious are of rare occurrence. In France the curative properties of arsenical waters have long been recognized, and the famous sanitarium of La Bourboule in the volcanic district of the Auvergne has achieved a wide reputation for the efficacy of its waters in certain forms of nervous diseases. Hygeia Spring, supplying the bath houses at the hotel in the Lower Geyser Basin, carries .3 of a grain of sodium arseniate to the gallon. The Yellowstone Park waters, while they carry somewhat less arsenic than those of La Bourboule, greatly excel the latter in their enormous overflow. It is stated that the entire discharge from the springs of La Bourboule, amounts to 1500 gallons per minute. The amount of hot water brought to the surface by the hot springs throughout the Park is by no means easily determined, although during the progress of our investigations we hope to make an approximate estimate. Some idea of the amount of hot water brought to the surface and carried off by the great drainage channels may be formed at the Midway Basin. According to the most accurate measurements which could be made, the discharge from the caldron of the Excelsior Geyser into the Firehole River during the past season amounted to 4400 gallons of boiling water per minute, and there is no evidence that this amount has varied within the last two or three years. The sample of the Excelsior Geyser water collected August 25th, 1884, yielded .19 grains of sodium arseniate to the gallon. It is impossible to say as yet what curative properties these Park waters may possess ,in alleviating the ills of mankind. Nothing but an extended experience under proper medical supervision can determine. I may say that no hot springs with which I am acquainted prove so delightful for bathing purposes and so agreeable in their action upon the skin.

Changes modifying the surface-features of the Park in recent times are mainly those brought about by the filling up with detrital material from the mountains, the valleys and depressions worn out by glacial ice, and those produced by the prevailing climatic conditions. Between the Park country and what is known as the arid regions of the west there is the greatest possible contrast. Across the Park Plateau and the Absaroka Range the country presents a continuous mountain mass seventy-five miles in width, with an average elevation unsurpassed by any area of equal extent in the northern Rocky Mountains. It is exceptionally situated to collect the moisture-laden clouds, which coming from the southwest precipitate immense quantities of snow and rain upon the cooled table-land and neighboring mountains. The climate in many respects is quite unlike that found in the adjacent country, as is shown by the meteorological records, the amount of snow and rainfall being higher, and the mean annual